

Modelling the Enablers of IT Adoption in Electric Vehicles based Small and Medium Scale Enterprises: An ISM Approach

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The increasing adoption of Electric Vehicles (EVs) has the potential to significantly mitigate air pollution and carbon dioxide emissions while offering advantages such as lower operating costs, reduced noise levels, and the absence of tailpipe emissions compared to internal combustion engine vehicles. Consequently, EV technology is emerging as a key pathway toward sustainable development in the automotive sector. These benefits have stimulated market competitiveness and encouraged substantial investments by developing nations, particularly in developing economies like India. The manufacturing of electric vehicles involves the troika of electronics, mechanical, and IT-based components/tools. In this scenario, it becomes essential to have rationalised auto ancillary Small and Medium Scale enterprises (SMEs) for electric vehicles. It has been observed that ICT tools, in every kind of SME, are playing a vital role in the holistic coordination of EV-based SMEs. To gain the advantages of implementing IT (information technology) tools, researchers and practitioners need to understand and model the relevant factors responsible for their implementation. The work has identified the Critical Success Factors (CSFs) affecting EV-based SMEs and analysed their interrelationships using Interpretive Structural Modelling (ISM) and MICMAC analysis. The findings highlight the most influential factors of IT adoption in EV SMEs by studying the interrelationship between the factors. Lastly, the study attempts to suggest some implications & prospects that the market leaders and stakeholders can follow to capture the advantages of these booming sectors for economic growth and sustainability.

Keywords: Critical success factors, EV auto ancillaries, Interpretative structural modelling, MICMAC analysis, Sustainability

Introduction

In terms of both economic impact and Research and Development (R&D) spending, one of the major contributing sectors in manufacturing is the automotive sector. Researchers are paying greater attention to putting more technology components in automobiles to improve both passengers' safety as well as control pollutants like NO_x, CO, SO₂, etc. The electric vehicle is a booming technology today in the sector of the automobile industry and is the key technology to achieve the sustainability goal. Role of EV sustainability was discussed by Günther *et al.*¹, Patel *et al.*² and Omahne *et al.*³ The admiration of Electric Vehicles (EVs) is gaining popularity due to environmental awareness as well as cost reduction. Sanguesa *et al.*⁴ discussed the EV technology and perspective of the near-term prospects for this industry.⁵ They emphasized that electric vehicles are expected to become a fundamental element of future

smart city ecosystems, alongside shared mobility solutions and advanced public transportation systems. While the adoption of EVs presents opportunities and challenges, their long-term prospects remain promising. Ongoing reductions in battery costs, coupled with increased investments in clean technologies under favourable economic conditions, are likely to accelerate vehicle electrification and support the achievement of sustainability objectives.⁵⁻⁸

With the introduction of modern technologies, which include technologies like Industry 4.0, artificial intelligence, and cloud computing, small and medium-scale enterprises or auto ancillaries are facing tremendous opportunities/challenges and causing upgradation in business in profound ways,⁹ irrespective of their revenue and number of employees.¹⁰ The flexibility and small size prove to be a strength for the application of digitalization and IT tools for these small-sized organizations, and improve the rate of innovation and evolution. Nkwabi and Mboya¹¹ mentioned the implementation of poor technology as one of the major constraints that are

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affecting the growth of SMEs. Chege *et al.* clearly indicated the positive influence on SME innovation by the application of ICT-based technology.¹² Kannabiran G & Dharmalingam discussed increased market competition along with the rapidly changing business scenarios, as the influencing factors for the adoption of IT tools in SMEs and highlighted the advantages, security concerns, and competitive pressure for implementation of IT tools for SMEs.¹³ Consequently, to enhance operational efficiency and achieve cost effectiveness, it is crucial for SMEs to employ IT tools in order to different functions of SMEs- financial, production, and technical. Electric vehicles, these days, are globally accepted automobiles and have high demand in the market. The challenges for electric vehicle SMEs, to meet the varying demand and quality factors, are thus complex; hence use of IT tools can give genuine rewards to become a successful partner in the EV supply chain.

With the increasing pollution and health hazards, internal combustion engine vehicles are getting criticism worldwide. In order to meet the agenda of Sustainable Development Goal (SDG) 7, electric vehicles are proving to be helpful to meet the goal. This is due to the fact that EVs have a substantial impact on the environment, and it becomes tedious for traditional supply chains to meet market requirements.¹⁴ Researchers and practitioners widely acknowledge that SMEs play an important role in the product flow and value creation, making effective supply chain management a critical priority. The transition toward electric vehicles has profoundly influenced the automotive industry, requiring strategic realignment across supply chains. Consequently, industry leaders must collaborate with governments and allied institutions to promote environmentally responsible practices, ensuring that EV manufacturers actively drive sustainability initiatives throughout the entire supply chain network.¹⁵

In this scenario, and due to the complexities involved along the EV supply chain, the adoption of IT tools is of utmost importance for the successful promotion of EV technology and attaining sustainability. Jabbor *et al.* discussed the implications of big data analysis and digital technologies on sustainable supply chains.¹⁶ For the proper implementation of IT tools and available digital technologies, the barriers that may retard the adoption process of newer technologies need to be recognised

and modelled. It, however, came to light that there exists a substantial research gap in this work.

The research gaps as found from the review are as mentioned below:

1. The categorisation of the key success factors influencing the implementation of Information Technology (IT) tools along the EV-based small and medium-scale enterprises needs to be focused.

2. The relevant factors for the adoption of IT tools of electric vehicle SME-based supply chains need to be analysed.

3. The structural interrelationship between the crucial success factors of IT adoption and digital technologies in the EV supply chain needs to be identified.

4. To identify and model the structural relationships among critical success factors related to IT adoption and digital technologies in the electric vehicle supply chain.

5. A viewpoint of all players along the supply chain needs to be incorporated to provide holistic insights to practitioners for the successful implementation of new IT technologies within EV-based SMEs.

The novelty of this study lies in providing in-depth insights into the adoption of information technology tools within electric vehicle-based SMEs through the application of Interpretive Structural Modelling (ISM). This approach (ISM approach) enables systematic exploration of the complex interrelationships among critical success factors influencing IT adoption. In this research, key factors affecting IT implementation across the EV supply chain are identified and structurally modelled, offering valuable guidance for formulating managerial and policy-level strategies. The proposed framework contributes operationally by supporting business performance enhancement while addressing emerging challenges in the rapidly evolving EV supply chain ecosystem.

The key contributions of this work include:

- Elicitation of key success factors for IT adoption in EV-based SMEs.
- Finding the structural relationship between these factors using ISM.
- Discussing the managerial implications of this study and suggesting directions for future work.
- In addition, the framework proposed in the present research has broad applicability and can be adopted to enhance the organisation's performance, administrative capabilities, and effectiveness.

Table 1 — Details of critical success factors

Details		
F1	Top management commitment	It is responsible for developing the long-term vision related to the survival and progress of the enterprise. ¹⁷⁻²²
F2	Employee attitude	Employees are the frontline workforce and induction of any positive change within the firm cannot be accomplished without the total commitment of the employees. ²²⁻²⁷
F3	Training and education of employees	Lack of training and education leads to a deficit in skills and IT knowledge, which ill-equips the employees to carry out their routine tasks, may lead to resentment among employees, a demotivated work environment, and lower efficiency. ^{22,23,27-30}
F4	Collaboration with OEMs	The OEM supports EV-SMEs in adopting ICT through training, knowledge sharing, and providing access to relevant tools resulting in increased efficiency, integration of the supply chain for the OEMs and support their JIT and other supply chain optimization initiatives. ^{18,19,31-33}
F5	Govt. policies	Governments can also play an important role by providing financial and technological support through relevant programs and subsidies like developing strong IT legislation and laws, knowledge sharing through industry-specific awareness programs etc. ^{18,26,31}
F6	IT infrastructure	The presence of technological infrastructure such as telecommunication facilities, software, hardware, low-cost and high-speed internet connection with suitable bandwidth facilitates the firms in integrating IT into their mainstream functions. ^{19,26,27,31,34}
F7	Work culture	This factor covers all the aspects of the work within the firm, such as performance orientation, in-group collectivism, change management, trust, transparency, teamwork, and other important indicators of an innovation-fostering workplace. ^{18,23,27,35,36}
F8	Market competitiveness towards the implementation of IT	Competitive pressure leads to evolution in a company's conventional business processes, making them a close approximation of other firms in the industry. ^{18,19,34,36}
F9	Supplier's collaboration to support IT	Integrating IT at all levels of the supply chain can lead to substantial gains in information sharing and collaboration with better coordination at all levels of the supply chain. ³⁷
F10	Availability of relevant IT tools	Unavailability of ICT tools tailored for EV-SMEs is a barrier to the adoption of IT, as most of the IT tools have been designed for larger firms, which leads to incompatibility between the business practices of SMEs and available tools. ^{18,26,28,29,36,38,39}
F11	Cost of IT tools	The lack of capital, the huge cost of IT adoption, usage, and maintenance are commonly observed factors affecting the various decisions of SME firms. ^{19,24,28,29,40,41}
F12	Information Security	A large number of SMEs are reluctant to use IT due to the host of security issues related to electronic payment, privacy, and data protection. ^{19,26,28,34,39,40}
F13	Impact of IT on the competitiveness of firms	IT adoption leads to better internal and external communication, optimization of the supply chain, reduced operating costs, and larger market exposure. ^{36,37}

Details of Critical Success Factors

The work focuses on studying and modelling the Critical Success Factors (CSFs) influencing the adoption/integration of IT tools and electric vehicles by SMEs. This section outlines the key CSFs required for the effective implementation of IT and ICT solutions across the EV supply chain. An extensive review of the existing literature was undertaken, and in conjunction with insights obtained from academic and industry experts, a total of thirteen CSFs were identified for analysis, as summarised in Table 1.

Methodology

Interpretive Structural Modelling (ISM) is a mathematically derived decision-making method that is based on multiple criteria used to model complex problems using a systematic procedure consisting of

well-defined steps.²² Many authors like Ribeiro *et al.*⁴², Shoar *et al.*⁴³, Palit *et al.*⁴⁴, and Mekonnen *et al.*⁴⁵ have implemented the ISM methodology, indicating its successful implementation in the wide domain of work. The flowchart for the ISM methodological framework adopted in this study is depicted in Fig. 1.

I. Structural Self-Interaction Matrix (SSIM)

The study leveraged the knowledge of experts from industry and academia to identify and model the relationships among the critical success factors. The SSIM was developed by drawing upon the contextual relationships between factors affecting IT adoption among electric vehicle-based auto-ancillary SME owners. The relationships between different factors are stated using four symbols below:

- A: q will lead to p ,

Table 3 — Initial reachability matrix

I/J	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13
F1	1	0	1	1	0	1	1	0	0	0	0	0	0
F2	0	1	0	0	0	0	1	0	0	0	0	0	0
F3	0	1	1	0	0	0	0	0	0	0	0	0	0
F4	0	0	0	1	0	0	0	0	0	0	0	0	0
F5	1	0	1	1	1	1	0	1	0	0	0	1	1
F6	0	0	1	1	0	1	1	0	1	1	0	1	1
F7	0	0	1	0	0	0	1	1	0	0	0	0	1
F8	0	0	0	0	0	0	0	1	1	0	0	0	0
F9	1	0	0	0	0	0	0	1	1	0	0	1	0
F10	0	1	1	1	0	0	0	1	1	1	0	0	1
F11	1	0	1	0	0	1	0	1	0	1	1	0	1
F12	1	0	0	1	0	0	0	1	1	0	0	1	1
F13	0	0	0	0	0	0	0	0	1	0	0	0	1

Table 4 — Final reachability matrix

I/J	1	2	3	4	5	6	7	8	9	10	11	12	13	Dependence
1	1	1	1	1	0	1	1	1	1	1	1	1	1	12
2	0	1	1	0	0	0	1	1	0	0	0	0	1	5
3	0	1	1	1	0	0	1	0	0	0	0	0	0	4
4	0	1	0	1	0	0	1	0	1	1	0	0	0	5
5	1	0	1	1	1	1	0	1	0	0	0	1	1	8
6	0	1	1	1	0	1	1	1	1	1	0	1	1	10
7	0	1	1	0	0	0	1	1	1	0	0	0	1	6
8	1	0	0	0	0	0	0	1	1	0	0	1	0	4
9	1	0	1	1	0	1	1	1	1	0	0	1	1	9
10	1	1	1	1	0	0	1	1	1	1	0	0	1	9
11	1	1	1	1	0	1	1	1	1	1	1	1	1	12
12	1	0	0	1	0	1	1	1	1	0	0	1	1	8
13	1	0	0	0	0	0	0	1	1	0	0	1	1	5
Dependence	8	8	9	9	1	6	10	11	10	5	2	8	10	

Table 5 — Level partitioning: Iteration (I – VII)

Factors	Reachability set, R(Fi)	Antecedent set, A(Fi)	Intersection set, I(Fi)
Iteration I			
F1	1,2,3,4,6,7,8,9,10,12,13	1,5,8,9,10,11,12,13	1,8,9,10,12,13
F2	2,3,7,8,13	1,2,3,4,6,7,10,11	2,3,7
F3	2,3,7,4	1,2,3,5,6,7,9,10,11,12	2,3,7
F4	4	1,4,5,6,9,10,11,12	4
F5	1,2,3,4,5,6,7,8,9,10,12,13	5	5
F6	2,3,4,6,7,8,9,10,12,13	1,5,6,9,11,12	6,9,12
F7	2,3,7,8,9,13	1,2,3,4,6,7,9,10,11,12	2,3,7,9
F8	1,8,9,12	1,2,5,6,7,8,9,10,11,12,13	1,8,9,12
F9	1,3,4,6,7,8,9,12,13	1,4,6,7,8,9,10,11,12,13	1,4,6,7,8,9,12,13
F10	1,2,3,4,7,8,9,10,13	1,4,10,11	1,4,10
F11	1,2,3,4,6,7,8,9,10,11,12,13	1,11	1,11
F12	1,3,4,6,7,8,9,12,13	1,5,6,8,9,11,12,13	1,6,8,9,12,13
F13	1,8,9,12,13	1,2,5,6,7,9,10,11,12,13	1,9,12,13

(Contd.)

Table 5 — Level partitioning: Iteration (I – VII) (Contd.)

Factors	Reachability set, R(Fi)	Antecedent set, A(Fi)	Intersection set, I(Fi)
Iteration II			
F1	1,2,3,6,7,9,10,12,13	1,5,9,10,11,12,13	1,9,10,12,13
F2	2,3,7,13	1,2,3,6,7,10,11	2,3,7
F3	2,3,7	1,2,3,5,6,7,9,10,11,12	2,3,7
F5	1,2,3,5,6,7,9,10,12,13	5	5
F6	2,3,6,7,9,10,12,13	1,5,6,9,11,12	6,9,12
F7	2,3,7,9,13	1,2,3,6,7,9,10,11,12	2,3,7,9
F9	1,3,6,7,9,12,13	1,6,7,9,10,11,12,13	1,6,7,9,12,13
F10	1,2,3,7,9,10,13	1,10,11	1,10
F11	1,2,3,6,7,9,10,11,12,13	1,11	1,11
F12	1,3,6,7,9,12,13	1,5,6,9,11,12,13	1,6,9,12,13
F13	1,9,12,13	1,2,5,6,7,9,10,11,12,13	1,9,12,13
Iteration III			
1	1,2,6,7,10,12	1,5,10,11,12	1,10,12
2	2,7	1,2,6,7,10,11	2,7
5	1,2,5,6,7,10,12	5	5
6	2,6,7,10,12	1,5,6,11,12	6,12
7	2,7	1,2,6,7,10,11,12	2,7
9	1,6,7,9,12	1,6,7,9,10,11,12	1,6,7,9,12
10	1,2,7,10	1,10,11	1,10
11	1,2,6,7,10,11,12	1,11	1,11
12	1,6,7,12	1,5,6,11,12	1,6,12
Iteration IV			
1	1,6,10,12	1,5,10,11,12	1,10,12
5	1,5,6,10,12	5	5
6	6,10,12	1,5,6,11,12	6,12
10	1,10	1,10,11	1,10
11	1,6,10,11,12	1,11	1,11
12	1,6,12	1,5,6,11,12	1,6,12
Iteration V			
1	1,6	1,5,11	1
5	1,5,6	5	5
6	6	1,5,6,11	6
11	1,6,11	1,11	1,11
Iteration VI			
1	1	1,5,11	1
5	1,5	5	5
11	1,11	1,11	1,11
Iteration VII			
5	1,5	5	5

Table 6 — Conical matrix

I\J	F4	F8	F3	F13	F9	F2	F7	F10	F12	F6	F1	F11	F5
F4	1	0	0	0	0	0	0	0	0	0	0	0	0
F8	0	1	0	0	0	0	0	0	0	0	0	0	0
F3	0	1	1	0	0	0	0	0	0	0	0	0	0
F13	0	1	0	1	0	0	0	0	0	0	0	0	0
F9	1	0	1	1	1	0	0	0	0	0	0	0	0

(Contd.)

Table 6 — Conical matrix (Contd.)

IJ	F4	F8	F3	F13	F9	F2	F7	F10	F12	F6	F1	F11	F5
F7	0	1	1	0	0	0	1	0	0	0	0	0	0
F10	1	0	0	0	0	0	0	1	0	0	0	0	0
F12	1	0	1	1	0	1	1	1	1	0	0	0	0
F6	1	1	1	1	0	0	1	1	1	1	0	0	0
F1	1	1	1	1	0	1	1	1	1	1	1	0	0
F11	1	0	0	1	0	1	1	1	1	0	0	1	0
F5	1	0	0	0	0	0	0	1	1	0	0	1	1

		INDEPENDENT						LINKAGE					
DRIVING POWER	12		11						1				
	11												
	10						6						
	9						10,12				9		
	8	5											
	7												
	6										7		
	5								2	4	13		
	4										3	8	
	3												
	2												
	1												
		AUTONOMOUS						DEPENDENT					
		1	2	3	4	5	6	7	8	9	10	11	12
		DEPENDENCE											

Fig. 2 — MICMAC analysis

V. MIC-MAC Analysis

In order to know the driver-dependence relationship, MICMAC analysis is done. This analysis aids in the interpretation of the key factors affecting IT adoption from among the variables selected for the study, which is based on the matrix multiplication properties.

The factors are grouped into four categories—autonomous, linkage, dependent, and independent—based on the analysis. This classification is based on each factor’s driving and dependence power, providing insights into their behaviour and influence within the system. The MICMAC Analysis as defined (Warfield⁴⁶) is shown in Fig. 2. The four quadrants represent the four categories of variables.

VI. ISM Model (Digraph)

This development of the ISM Model is the culminating step of the ISM methodology. The ISM Model is created using nodes and edge lines based on the final reachability matrix's conical matrix

configuration. The factors/variables of the system are represented by the nodes and the relationship of the form - node ‘X’ leads to node ‘Y’ – is shown with the help of a directed line, thereby giving it the name of ‘digraph’, i.e. directed graph. The digraph is structured in accordance with the following two principles: (i) Any two distinct lines cannot be parallel and (ii) No loops are allowed. The ISM Model provides a visualization of the structure of contextual relationships among the CSFs for the system under study. The ISM model has been presented in Fig. 3.

Discussion

In the present work, the key critical success factors are identified for the implementation of IT tools to electric vehicle SMEs in order to achieve sustainability goals. ISM is used as a methodology to find the interrelationships between these key critical success factors. The key findings from the analysis conducted in the study are summarised:

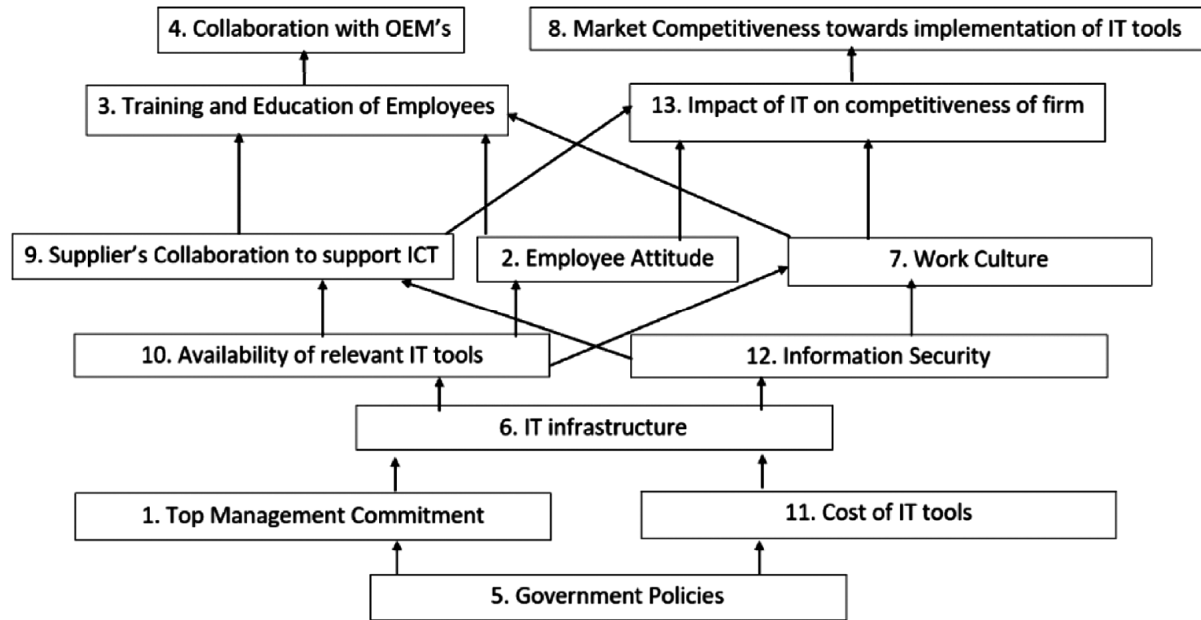


Fig. 3 — ISM model

- None of the identified factors in this study is an autonomous factor, which clearly indicates that all the factors considered here have substantial significance for IT adoption in EV-based auto-ancillary SMEs. Thus, the managers of the auto-ancillary for electric vehicles should give appropriate consideration to all the identified factors.

- Factors 1 (Top Management Commitment) and 9 (Supplier's Collaboration to support ICT) are found to be linkage variables from the driver-dependent relationships found through MIC-MAC analysis. This implies that these components have a strong driving force and are highly dependent on other factors. Both these factors need added supervision from the management of the firm as these are unstable factors that can change the course of the IT adoption process.

- Factors 5 (Govt. Policies), 11 (Cost of IT tools), 10 (Availability of relevant IT tools), 12 (Information Security), and 6 (IT infrastructure) are the independent variables that have high driving power and weak dependence. These are the self-governing, high-impact factors suitable for the adoption of IT tools by EV-SMEs.

- Factors 3 (Training and Education of Employees), 4 (Collaboration with OEMs), 2 (Employee Attitude), 7 (Work-culture), 8 (Market Competitiveness towards implementation of IT tools), 13 (Impact of IT on the competitiveness of the firm) are the dependent factors with weak driving power.

These factors are influenced by independent factors and a host of other external elements.

- Government Policies (5) is the most basic influencing factor among all the identified factors. This is because the government policies determine the legal and financial infrastructure available for the implementation of IT tools. These policies determine the level of information security being provided by the IT firms, the speed of conflict resolution, data protection, and cost reduction through subsidies. The availability of automotive-specific IT tools can also be influenced by the government through its digital initiatives. Our findings are in line with the previous research conducted on SMEs as well as automotive firms in developing countries for the adoption of new technologies, including IT.

Practical/Managerial Implications

The practical aim of this work is to offer strategic guidance for facilitating the easy implementation of IT tools in small and medium-scale enterprises. Based on the study done, it is found that the competency and persistence of the top management towards the implementation of IT tools drive the entire enterprise towards successful integration of ICT. This also helps the firm to reap substantial positive benefits in productivity, efficiency, and profits. The cost of IT tools remains an eminent resistance to ICT adoption in the field. The financial constraints of the company

and the incremental effect of ICT adoption on profits, guide the auto-ancillary SME decision on ICT adoption.

Amid widespread concerns regarding data theft and privacy, worldwide cyberattacks, including ransomware and malware attacks, raise deep concerns among automotive firms regarding IT adoption. Thus, information security becomes a central issue whose resolution can bolster the confidence for IT adoption among the existing SMEs, including EV-based SMEs.

The impact of ICT on a firm's baseline requirements, such as an increase in productivity, efficiency, market exposure, and a reduction in operating costs and delivery time, is highly dependent upon the depth of integration of ICT in the firm's day-to-day operation. Though the return on investment of ICT adoption is high, the visible impact on profits in the short-term is marginal because the result on profits is incremental and is visible in long-term effective implementation, as also noted in previous research.

Conclusions

The increasing emphasis on sustainability and governmental policies is accelerating the transition towards Electric Vehicles (EVs), making their incorporation into supply chains more viable. For Small and Medium Enterprises (SMEs) focused on EVs, leveraging IT and ICT tools effectively is essential to tackle supply-chain obstacles and maintain long-term competitiveness. Although the pace of technological advancement in the automotive industry has been sluggish, EV SMEs can secure competitive advantages through gradual improvements driven by IT. However, there is a scarcity of research on the adoption of IT among auto-ancillary SMEs that focus on EVs. This study highlights thirteen key success factors based on existing literature and employs Interpretive Structural Modelling to examine their interconnections, allowing firms to prioritize the main enablers for successful IT integration.

This research, due to its inherent goal, is limited by its scope only to auto-ancillary EV-based SMEs. Despite ISM being a tried and tested tool, it suffers from inherent deficiencies due to only qualitative treatment of variables. Thus, the model needs statistical validation. Structural Equation Modelling can be used to develop thorough quantitative evidence for the given model. Although the

findings of this research paper are in line with research conducted on new technology adoption in SMEs in developing countries, this statement needs to be further verified through future work.

Data availability: The dataset generated and used for this work is available with the corresponding author and may be provided on request.

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